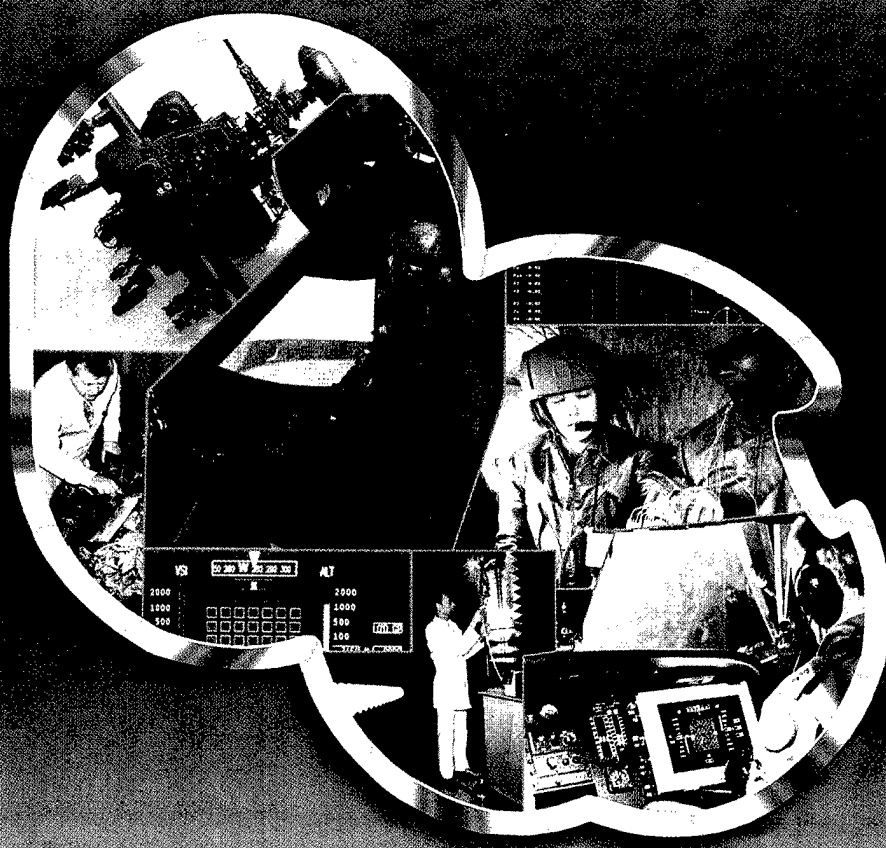


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Facial Injury and Night Vision Goggles in U.S. Army Helicopter Accidents 1980-2000

by John S. Crowley and Paul A. Cain



Aircrew Protection Division

June 2001

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and 31.9 injured per 100 Class A accidents. There was no difference in injury rate between NVG types or when compared to AH-64A HMD injuries. An FPV might have prevented, or reduced in severity, as much as 85 percent of the injuries.

Conclusions: Despite the reassuringly few injuries, serious injury remains a possibility, even in the current generation of aircraft. If a piece of equipment could be devised that prevented the NVGs from hitting the face, but did not have the adverse features of the FPV, injury rates would be reduced and flight safety maintained.

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United States Army accident data are not subject to any distribution limitation when identifying details are omitted, but do carry the following usage limitation:

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Introduction

Night Vision Goggles (NVGs) and other varieties of helmet-mounted displays (HMDs) have become an essential part of military flight operations. The first operational NVGs in the U.S. Army, AN/PVS-5, were introduced in the early 1970s and were based on second-generation image intensifier (I²) tubes. These were originally available only in a full-face configuration (Figure 1) that allowed no peripheral vision or look-under capability, and were gradually replaced for aviation use by the “cutaway” version. Third generation I² devices, called the AN/AVS-6 Aviator’s Night Vision Imaging System (ANVIS) (Figure 2), have replaced the AN/PVS-5 in U.S. Army aviation. Other HMDs in operational use include the helmet display unit (HDU) worn by Apache attack helicopter pilots, which provides a monocular image based on temperature contrast in the environment.

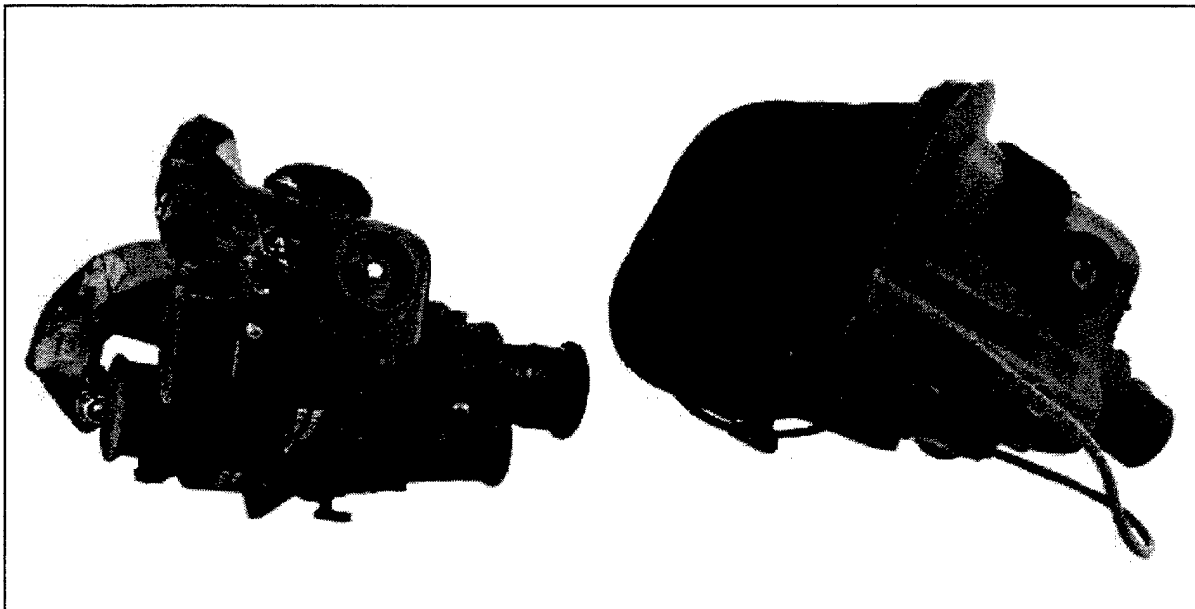


Figure 1. “Cutaway” AN/PVS-5 (left) and original AN/PVS-5 (right).

While these devices can provide an immense tactical advantage, they also present the aviator with a variety of human factors challenges and potential safety hazards. The effects of the degraded visual environment on flight performance and pilot orientation have been extensively reviewed (Verona, and Rash, 1989 and Rash, Verona, and Crowley, 1990), but crash safety has received less attention in the aeromedical literature. Shannon and Mason (1997) hypothesized that the increased mass and adverse center of gravity associated with NVGs would increase the risk of head and neck injury and this was found to be the case in their study. Additionally, there was a small, although not significant, difference between AN/PVS-5 and ANVIS, which they speculated might be due to a feature seen in the ANVIS, but not the

AN/PVS-5, that allows the tubes to break away from the helmet at 10-15G during an accident. This same feature may also allow the NVGs to clear the face in an accident and protect against direct trauma. However, horizontal velocity and pitch angle were greater in the NVG accidents in this study and the NVGs themselves were not shown to be the physical cause of the injuries. While neck injury is a significant concern, head injuries account for 22.9 percent of all injuries in survivable U.S. Army helicopter crashes, and the most common injury mechanism is contact with objects within the cockpit (Shanahan and Shanahan, 1989). In 37.5 percent of cases, the helmet is struck on the front, in the area of the visor and on the visor cover (Vyrnwy-Jones, Lanoue, and Pritts, 1988). The extent of facial injury caused by direct contact with NVGs remains unclear, but the potential for harm is evident (Figure 2).



Figure 2. ANVIS

Visual aids such as HMDs must be worn extremely close to the aviator's eyes and face, thereby constituting a potential injury hazard. The rationale for concern is not that the NVGs or HDU will independently cause injury, but rather that in a crash, an otherwise blunt impact from a cockpit surface could be transmitted through the NVG/HDU and focused on critical structures such as the eye or orbit. Surprisingly, the monocular HMD used by U.S. Army AH-64 Apache pilots has been found to account for only 4 injuries out of 50 Apache accidents; none of these injuries was severe or had any lasting sequelae (Crowley, 1998).

To date, there has been no published analysis of the injuries caused by NVGs, but mannequin testing in the United Kingdom has shown that NVGs can impact the face during decelerations of less than 15 Gx (Johnson, 1996). Because of this concern, British Army helicopter pilots using NVG without a “break away” mounting are recommended to use a polycarbonate face-protective visor (FPV) (Taylor, 1990) that is worn between the NVG tubes and the eyes (Figure 3). However, pilots have reported that the FPV is uncomfortable and distracting, and visor fogging or scratching can be a problem, possibly increasing the chance of an accident. In the U.S. Army, facial protection is not provided as a routine to HMD users although a prototype protective visor has been designed for the HGU-55 series helmets for use with NVGs in fixed wing aircraft. This is similar in concept to those used by the British military. Ametropic NVG-users are issued spectacles fitted with polycarbonate lenses, as NVG tubes have been shown to easily shatter glass lenses; these may provide a limited amount of protection (Crosley, 1988).



Figure 3. British Army FPV with fixed mount NVGs.

The objectives of this study were to determine the frequency and nature of NVG-related facial injury by examining the U.S. Army accident database and to assess the potential benefit of facial protection on the frequency and severity of these injuries.

Method

The U.S. Army Safety Management Information System (ASMIS) computerised database was searched for accidents involving injuries related to NVGs. Accidents in the U.S. Army are graded according to cost and injury severity. Current accident classification criteria are summarized in Table 1 (Department of the Army, 1987). The database was searched for relevant survivable or partially survivable (hereafter combined and referred to as 'survivable') Class A-C accidents from 1980 to 2000, inclusive. Accidents were sought in which an injury had been formally attributed to the NVGs. Several ASMIS data fields were searched, including those involving injury mechanism as well as those describing survival equipment factors. Separately, searches were performed to provide denominator data (e.g., number of NVG accidents, etc.). Two primary training aircraft in the ASMIS rotary-wing database, the TH-67 and the TH-55, are not used for NVG flying and these are excluded from the totals; otherwise all accidents are included.

Table 1.
U.S. Army aircraft accident and incident classifications.

Accident Class	Property Cost	Injury Severity
Class A	>\$1,000,000 or total loss of aircraft	Fatality or permanent total disability
Class B	>\$200,000	Permanent partial disability or >4 days in hospital
Class C	>\$10,000	Lost work time case
Class D	>\$2,000	Any other injury requiring treatment
Class E	>\$2,000	None

Note: Meeting the criterion for either cost or severity will place an accident in a specified class.

To estimate the potential effect of FPV use on the NVG injury rate, the NVG-related injuries found in the ASMIS search were classified into three categories based on injury location (Table 2). For this analysis, it was assumed that an FPV could be integrated into the HGU-56/P helmet and that the FPV would perform as designed.

Table 2.
Effect of FPV by injury location.

Effect of FPV on Injury	Injury Location
<u>Probably would</u> have been reduced or prevented	Eye, forehead, zygoma
<u>Possibly would</u> have been reduced or prevented	Face (general), nose, cheek, maxilla
<u>Probably would not</u> have been reduced or prevented	Lip, chin, mandible

Results

During the study period, 3179 Class A-C helicopter accidents occurred. Of these, a total of 347 survivable and 35 nonsurvivable accidents actually involved the use of NVGs. Table 3 shows the distribution by accident Class.

Table 3.
U.S. Army rotary-wing accidents 1980-2000.

	Accident Severity Class			
	A	B	C	Total
All accidents (excludes TH67 and TH55)	584	269	2,326	3,179
Survivable Accidents	463	269	2,326	3,058
Survivable Accidents with NVG	72	32	243	347

The severity of accidents with NVGs in use was compared to that of non-NVG accidents. There were 35 nonsurvivable Class A accidents involving NVGs and 86 nonsurvivable Class A accidents without NVGs. Although Class A accidents with NVGs were less likely to be survivable than non-NVG Class A accidents (72/107 vs 391/477, $\chi^2 = 11.47$, $p < 0.001$), the majority (67.3 percent) were still survivable. Overall, 96.2 percent of Class A-C helicopter accidents and 89.9 percent of NVG accidents were survivable.

In survivable Class A-C helicopter crashes occurring during the study period, 35 NVG-related injuries were sustained by 28 people in 21 aircraft. Most injuries were classed as "minimal" or "minor" and only 7 were "major" (Table 4), according to somewhat arbitrary U.S. Army criteria in effect until 1993 (Department of the Army, 1987). The seven major injuries consisted of one forehead and one orbital laceration, one eye hemorrhage (in a pilot killed by other multiple injury-producing mechanisms), and four facial fractures in three victims. Figure 4 shows the distribution of injury sites.

Table 4.
Severity of injury caused by NVGs.

Injury Severity	Number
Minimal	17
Minor	11
Major	7
Critical	0
Fatal	0

Table 5 presents the types of injuries seen and reveals that lacerations, abrasions and contusions were the most common.

Table 5.
Types of injury caused by NVGs.

Injury Severity	Number
Laceration	12
Abrasion	8
Contusion	8
Fracture	5
Hemorrhage	2

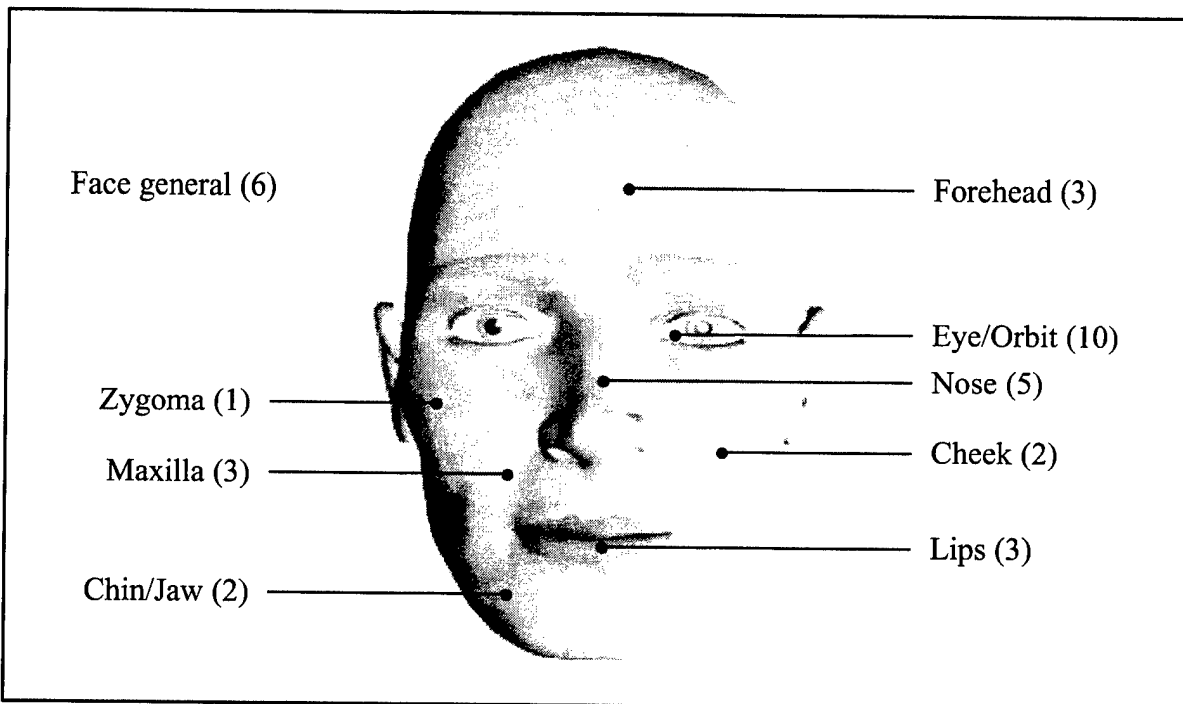


Figure 4. Facial injury sites.

Since flight hours with NVGs in use were not tracked by the U.S. Army until 1992, it is not possible to express injury risk in terms of flight hours of exposure. However, considering only survivable accidents in which NVG were worn, 6.1 percent of Class A-C accidents (21/347) and 26.4 percent of Class A accidents (19/72) involved an NVG-related injury. This risk to the individual would vary with the number of NVG wearers on board.

Another approach is in terms of the risk to an individual NVG user who is involved in a mishap. This calculation considered only cockpit occupants, as it was not known how many occupants in the passenger compartment were using NVGs. Both cockpit crewmembers were assumed to be wearing NVGs. A cockpit occupant wearing NVGs had a 3.6 percent chance

(25/694) of NVG-related injury if he or she was involved in a survivable Class A-C accident and a 16.0 percent chance (23/144) in a survivable Class A accident. Thus, there were 7.2 injured cockpit occupants per 100 Class A-C survivable accidents in which NVGs were worn, and 31.9 injured per 100 Class A accidents in which NVGs were worn.

The NVG type had no significant effect on injury rate in cockpit occupants; 14.3 percent (4/28) of AN/PVS-5 users and 15.6 percent (15/96) of ANVIS users suffered injury in Class A survivable mishaps. The NVG type was not specified in 10 Class A accidents, one of which involved an NVG-related injury. Again, it is not possible to determine the number of cabin occupants using NVGs and thus further analysis is precluded.

The 35 NVG-related injuries found in this study were reviewed to estimate the outcome had an FPV been worn. This analysis revealed that 14 injuries probably would have been prevented or reduced, 16 might have been prevented or reduced, and the FPV probably would not have helped in 5.

Discussion

Limitations

As this is a retrospective review of the accident database, injury rates may have been over- or underestimated for several reasons. There may have been simple errors by investigators, flight surgeons, data transcribers or computer data entry personnel, and the large number of NVG accidents precluded a manual review to verify correct data entry. Secondly, there appears to be a tendency for minor injuries to be unrecorded in victims suffering multiple severe injuries. This can be a major problem for nonsurvivable accidents, and may have occurred in severe but survivable accidents as well. For example, a victim with severe thoraco-abdominal trauma and extremity amputations is unlikely to have every minor facial laceration recorded in the ASMIS computer. Also, the injury data fields of the ASMIS database have been improved several times over the past 25 years and injury data from 1972-1983 is sometimes incomplete. The overall effect is for injuries to be underreported, particularly for AN/PVS-5; but the overall findings are unlikely to be significantly altered. Finally, although the British Army has integrated an FPV with its helmet, such a device has not been constructed for use with the HGU-56/P helmet.

Survivability

The fact that NVG accidents tend to be less survivable is clear in this study as it was in the study completed by Shannon and Mason, and it may be thought that there is little point in protecting against NVG injuries if there is a high risk of death from other injuries. While it is true that accidents occurring with NVGs in use are significantly more likely to be non-survivable than those without NVGs, the vast majority of NVG accidents are at least partially survivable. Even if only Class A accidents are considered, two-thirds of NVG accidents remain at least partially survivable. It is most important, therefore, to ensure that the NVGs are not responsible

for a severe injury that might be the sole cause of death or disability in an otherwise survivable accident.

Injuries

It is surprising that there have been so few injuries due to NVGs considering the proximity of the eyepiece lens of the intensifier tubes to the eyes and face, and certain design features may be the reason for this finding. The older AN/PVS-5 full faceplate design distributes any force across the user's brow; thereby spreading out impact loads and keeping the tubes clear of the eyes (Figure 1). The tubes of the cutaway AN/PVS-5 are more exposed and similar to the arrangement seen in ANVIS, but without the breakaway feature that might prevent the NVGs from impacting the face in some accidents. Unfortunately, the database does not differentiate between the two types of AN/PVS-5 and anyway, numbers are small. Overall, no difference in injury risk was found between ANVIS and the older AN/PVS-5.

As expected, the face in general, eyes and nose received the most damage with laceration, abrasion and contusion being the most common injury types. Although less common, fractures accounted for most major injuries. Whilst the risk of an injury related to NVGs might appear high, particularly in Class A accidents, this includes all 35 injuries no matter how severe. The risk of major injury is much lower. In fact, over the whole period of the study, there were only seven major injuries, one every three years.

The Apache HDU offers a chance to compare injury rates with another type of HMD. NVGs might be expected to cause injury more frequently than the HDU for several reasons. First, NVGs cover more facial surface area than the HDU, presenting a greater chance of being caught between a flailing face and the cockpit structure. Second, NVGs in the "stowed" position above the helmet can, with a small amount of force, rotate down toward the face. The stowed position for the HDU, in contrast, is rotated away from the face, arguably a safer location. Finally, although the HDU places a potentially dangerous polycarbonate transparency very close to the aviator's eye, the HDU shaft usually rests on the maxilla, which theoretically would minimize dynamic overshoot in the event of a direct impact. Notwithstanding these differences, the two basic varieties of HMDs in current U.S. Army use, NVGs and the Apache HDU, appear to present a similar overall risk of facial injury. An AH-64A crewmember had a 4 percent chance of an HDU-related injury in a Class A-C survivable accident and a 13.8 percent chance in a Class A accident (Crowley, 1998). In the aircraft included in this study, there was a 3.6 percent chance of NVG-related injury in a Class A-C survivable accident and a 16.0 percent chance in a Class A accident.

The conditions that produced injuries may change over time. The relative proportions of aircraft types in the Army have certainly changed, and modifications have been made to each aircraft type. Individual aircraft crash dynamics and crashworthiness may play a role that has not been demonstrated with the relatively few injuries in this study. Nevertheless, the hazard remains as the NVGs are so close to the face, and the possibility of a serious injury in future accidents cannot be ruled out.

Prevention

The analysis of potential FPV benefit is subjective and possibly unrealistic because it assumes that the device will always function as designed and not in itself cause injury. Although an FPV has actually been worn in an NVG accident, there was no evidence that the faceplate was struck (Braithwaite, 2001) and so, its operational performance is unknown. Nonetheless, this analysis suggested that if the FPV functioned as designed, as many as 85.3 percent (29/34) of the NVG-related injuries seen in this study could have been prevented or reduced in severity.

The potential benefit of an FPV must be weighed against the liabilities described above. If the device does not gain aircrew acceptance then it may not be fully utilized, and this might prove to be the case in the British Army. Indeed, a visor may not be the only, or best method of preventing the NVGs striking the face. Several methods of detaching NVGs from the helmet of fast jet aircrew have been examined for the U.S. Navy (Reh, Schmidt, and Greth, 1990). Although primarily aimed at reducing neck loads during ejection, some of these systems could remove the NVGs from in front of the face and reduce the risk of injury.

Conclusion

In the 347 survivable Class A-C U.S. Army helicopter accidents involving the use of NVGs between 1980 and 2000, inclusive, 28 aviators in 21 aircraft suffered 35 facial injuries that were definitely ascribed to NVG. Most (80 percent) NVG-related injuries were "minimal" or "minor," and none was life threatening. In survivable NVG accidents, there were 7.2 injured cockpit occupants per 100 Class A-C survivable accidents and 31.9 injured per 100 Class A accidents. There was no difference in injury rate between NVG types or when compared to the AH-64A HDU.

If an FPV functioned as designed, as much as 85.3 percent of the NVG-related injuries in this study might have been prevented or reduced in severity; but its safety in use has been questioned. Future changes to rotary-wing aircraft may modify or even increase the risk of injury and, despite the reassuringly few injuries in this study, serious injury remains a possibility due to the proximity of the NVGs to the eye and orbit, even in the current generation of aircraft. If a piece of equipment could be devised that prevented the NVGs hitting the face but did not have the adverse features of the FPV, injury rates would be reduced and flight safety maintained.

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